Ecosystem responses to experimental hydraulic variation: A tool for developing and validating instream flow models

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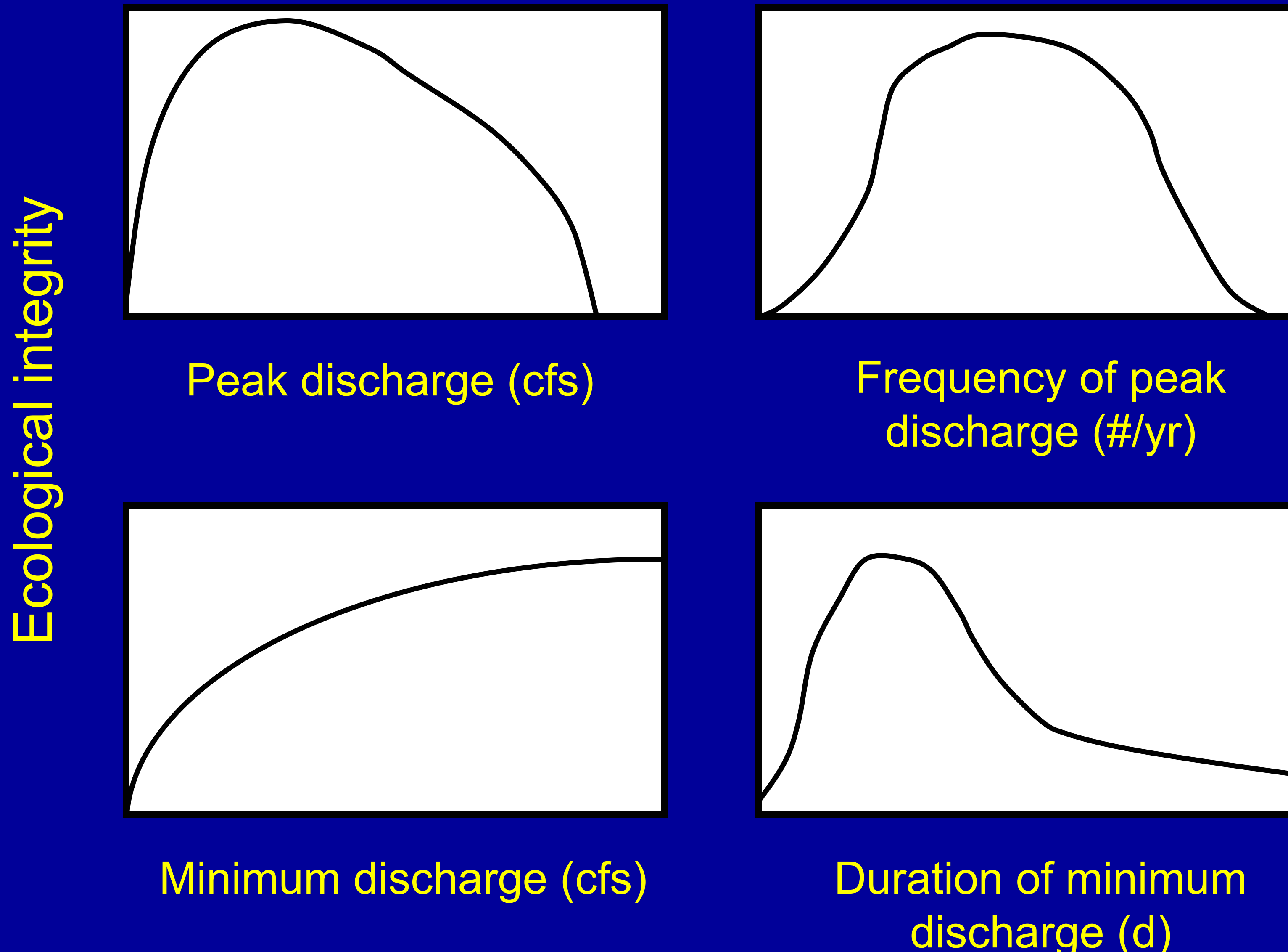
Overview of presentation

- Decision-making context for developing models to predict ecological flow requirements
- Need for improved understanding of stressor-response relationships
- Empirical challenges of predicting ecosystem responses to flow
- Use of experimental approaches to help predict flow responses
- Strategies for adding experimental approaches to the process of model development and validation

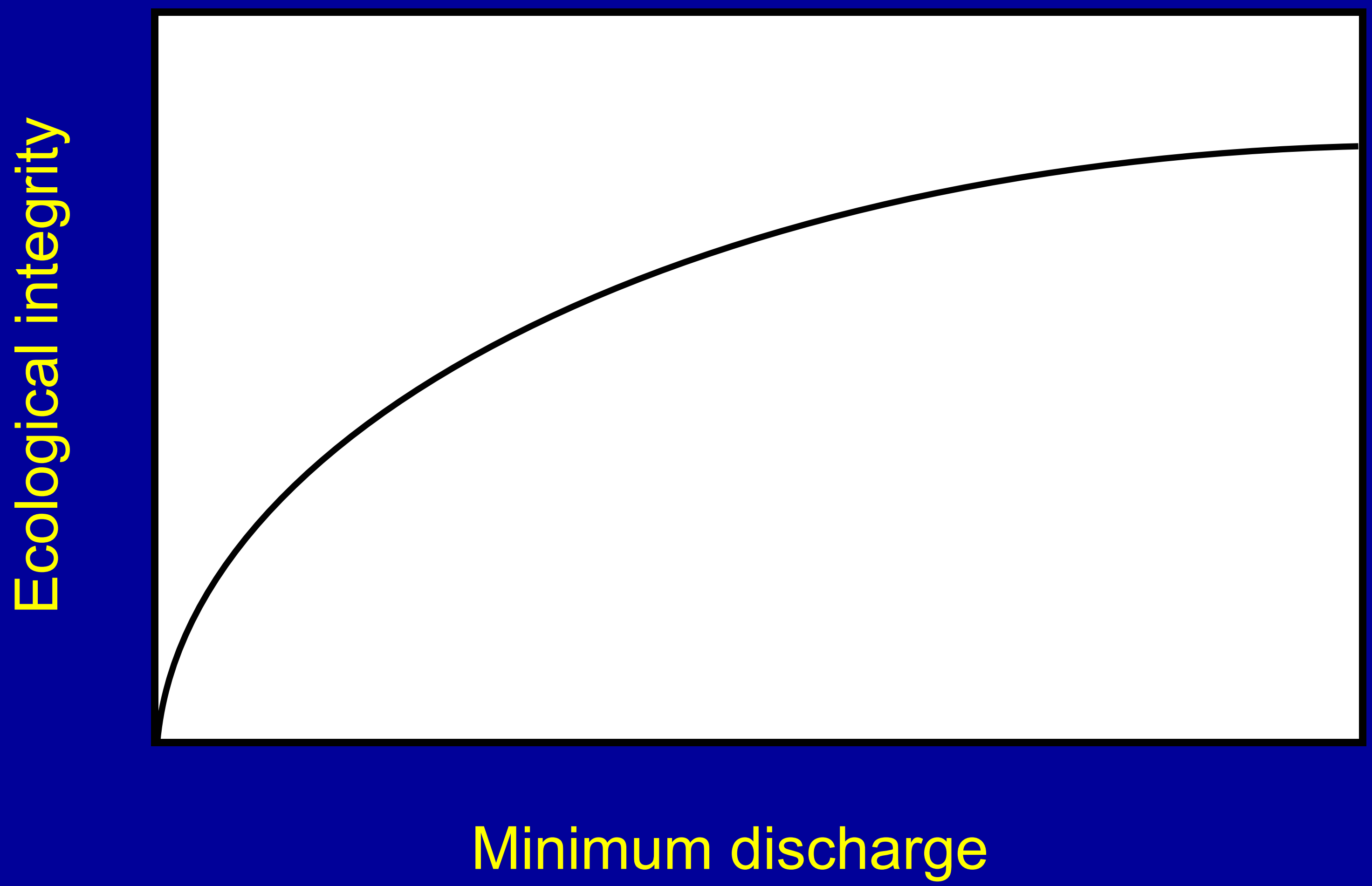
Decision-making context for flow management decisions

- Stakeholders often have different values and goals regarding “best uses” of limited water resources
- Requires ability to examine potential trade-offs involved with alternative flow allocation strategies
  - Need to predict how key ecosystem components will respond to specific changes in flow
  - Need to define level of uncertainty associated with predicted responses

Potential relationships between ecological integrity and flow characteristics



Using stressor-response relationships to predict ecosystem responses to flow changes



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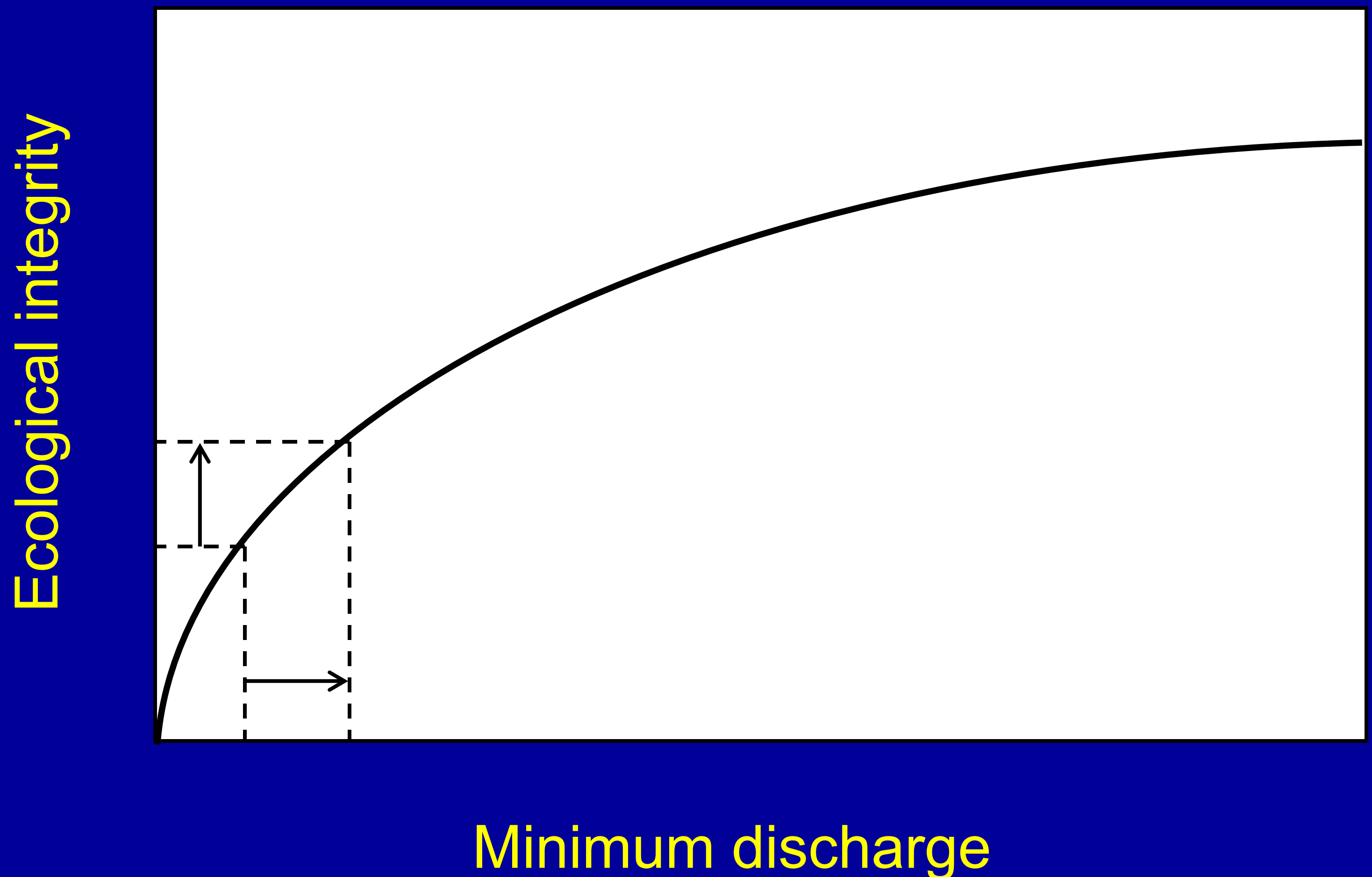

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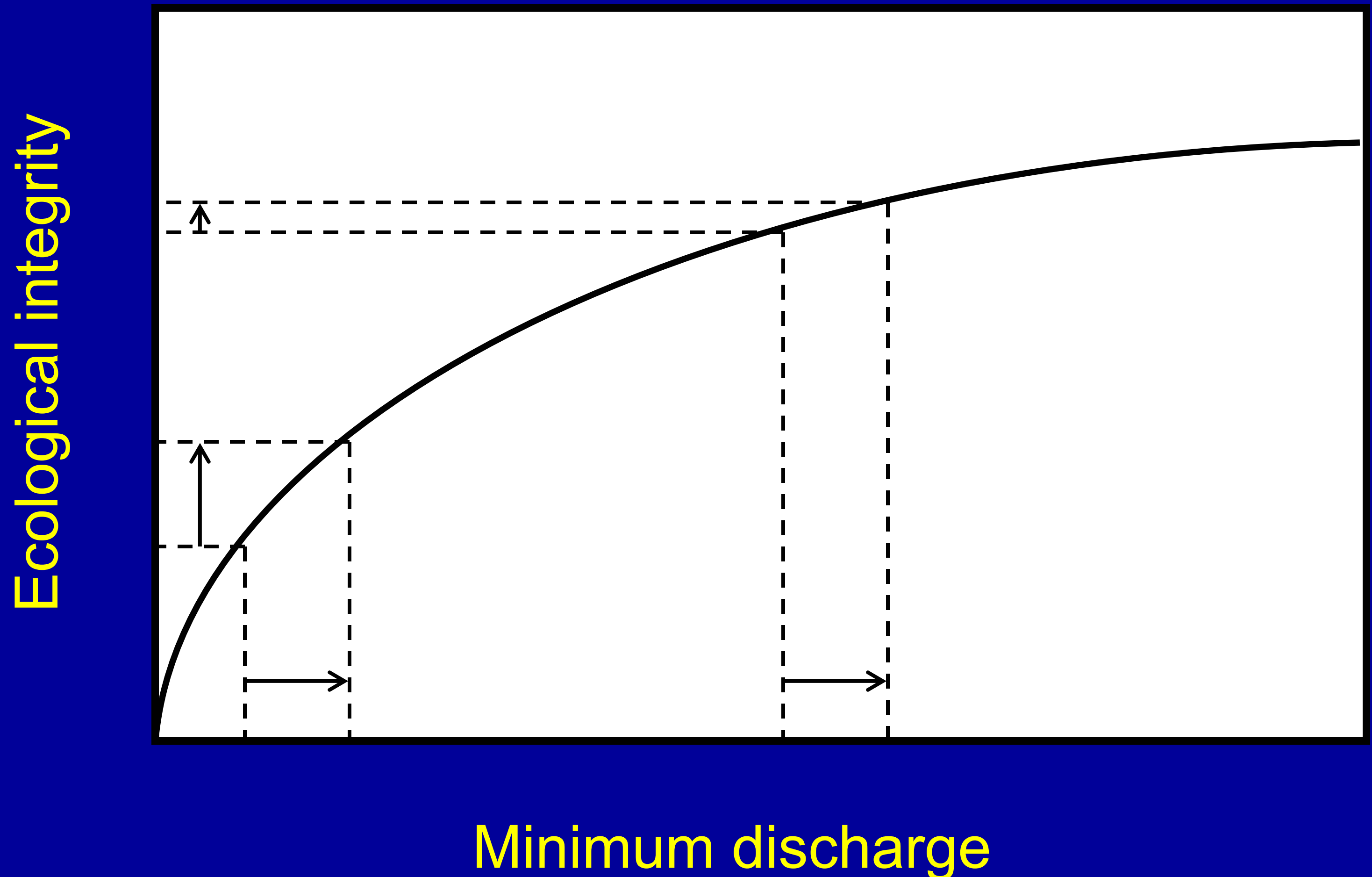

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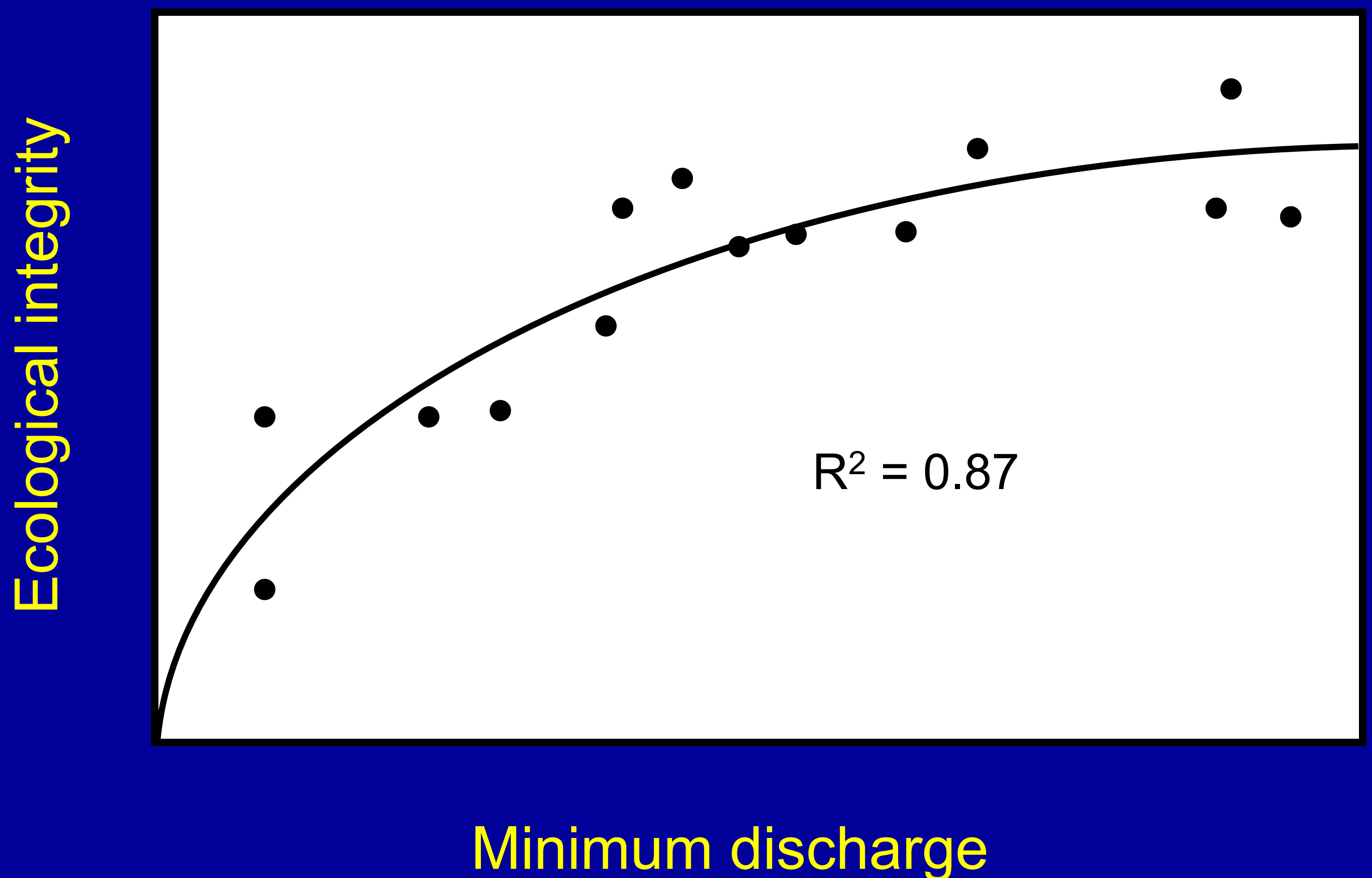
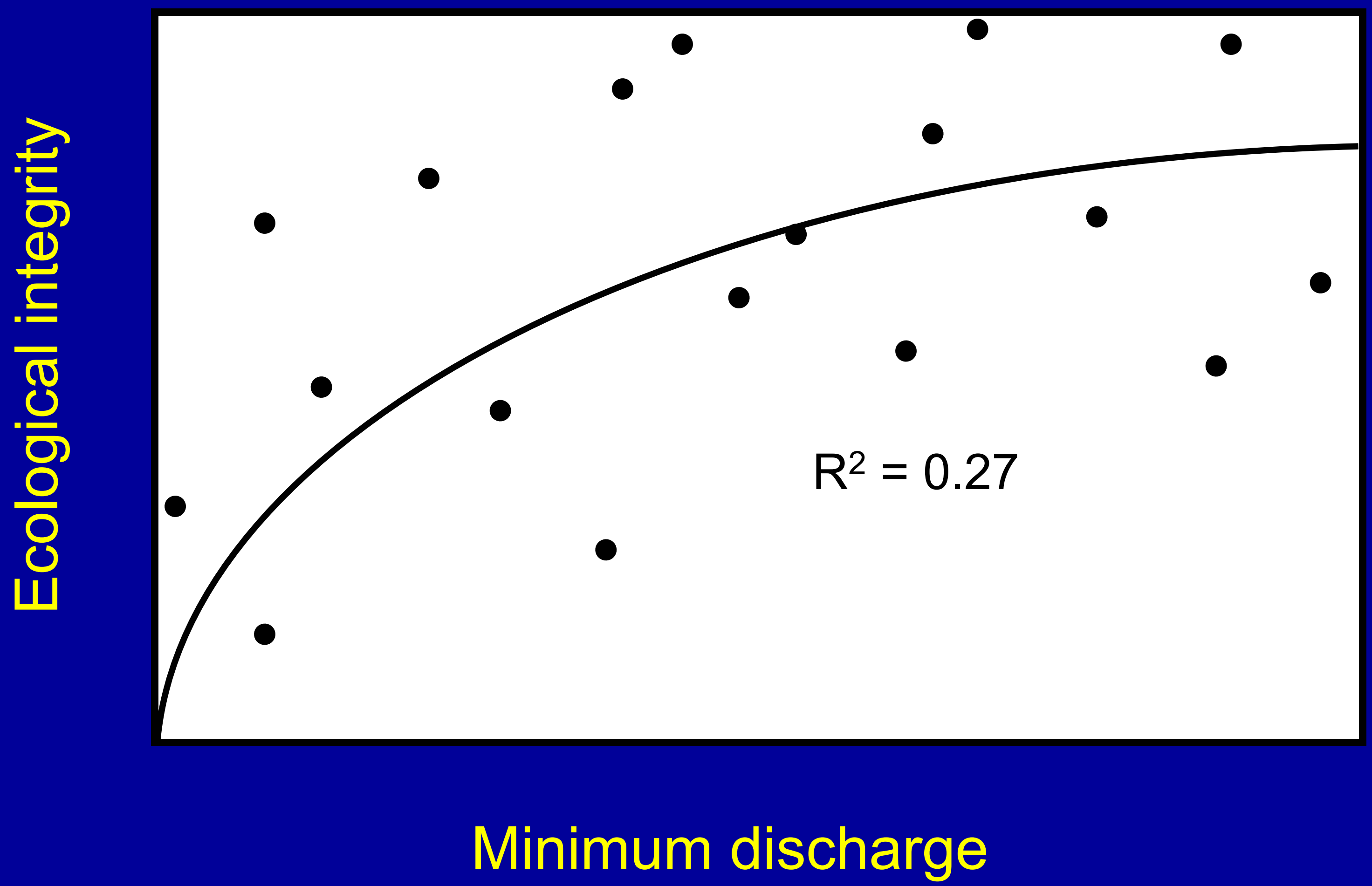


Using stressor-response relationships to predict ecosystem responses to flow changes



Sources of uncertainty in stressor-response models

- Identification of actual causal factor(s) governing ecological response
- Measurement error for independent and dependent variables
- Temporal variation in relationship (e.g., among seasons, between years)
- Spatial variation in relationship (e.g., among reaches, between rivers)

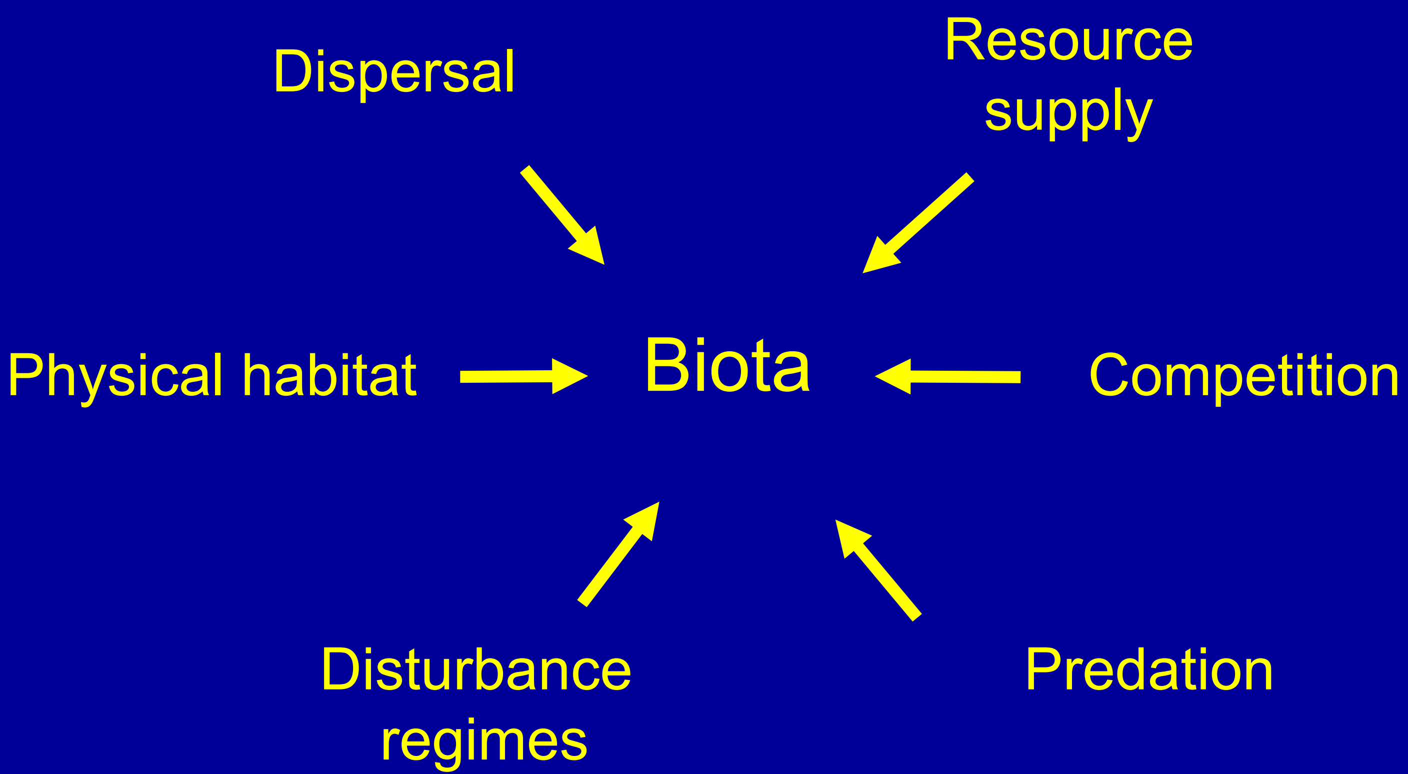
How are abundance – flow relationships used in predicting biological responses to flow changes?

Key assumption: Biotic distributions reflect physical habitat preferences

Physical habitat (Velocity, depth, cover) → River biota

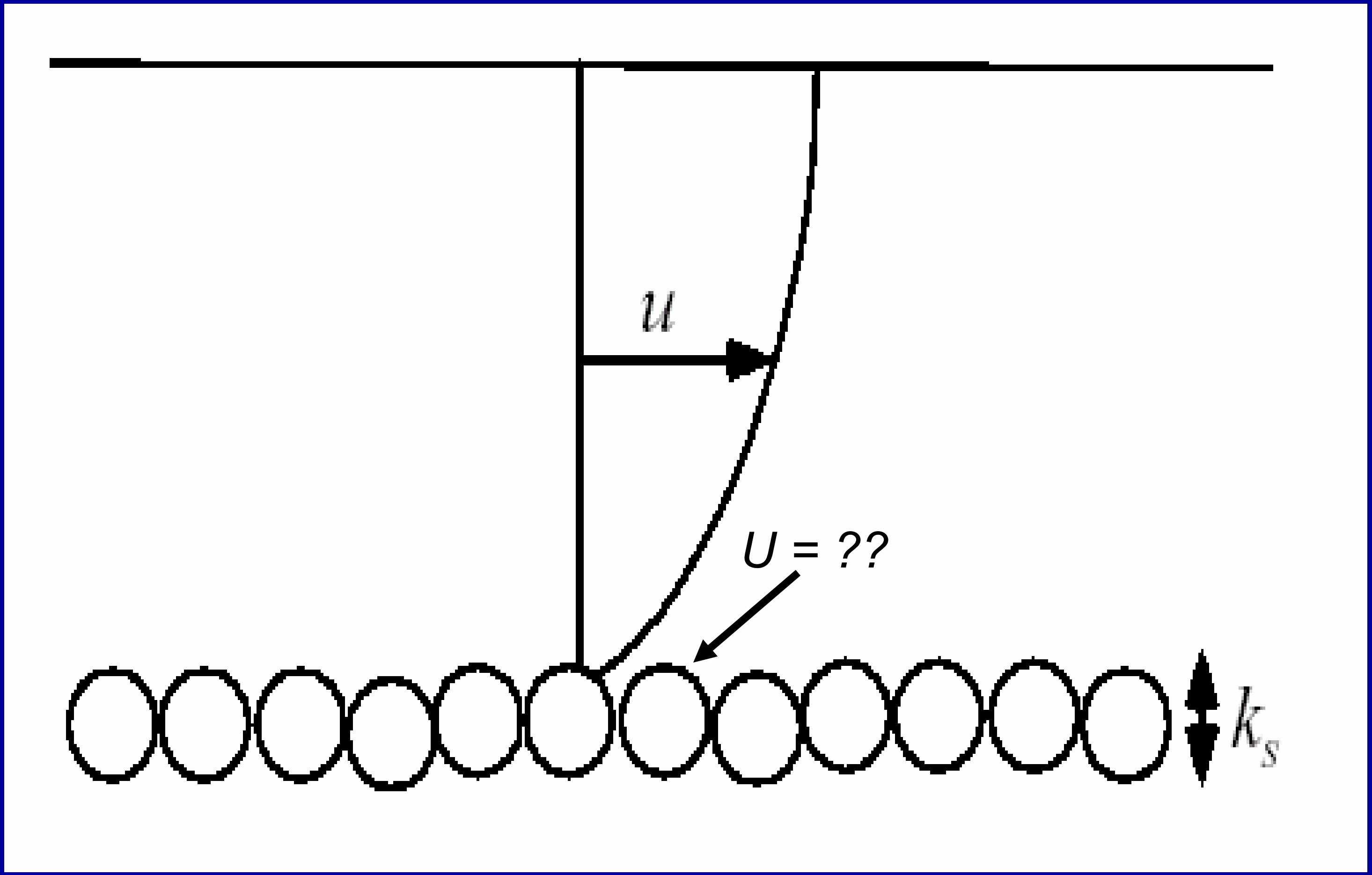
Flow affects river biota via multiple causal pathways

(Hart and Finellli. 1999. Ann. Rev. Ecol. Syst.)

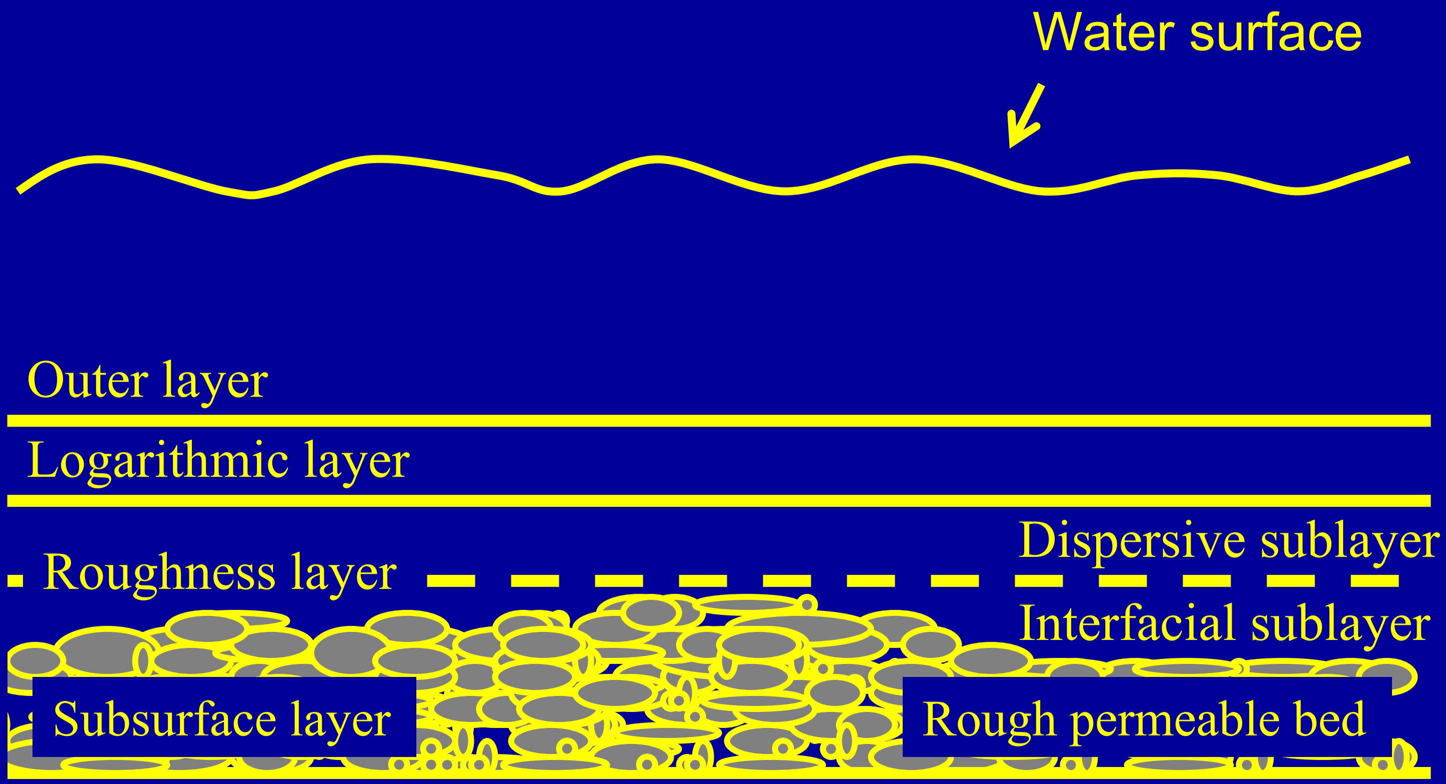


It can be difficult to quantify hydraulic habitats inhabited by some key components of river food webs

Above the river bed, velocity changes in a predictable way with height



Hydraulically rough flow is the norm in most rivers, which makes it difficult or impossible to predict near-bed velocities from measurements made higher above the bed



Not to scale

(Hart and Finelli. 1999. Ann. Rev. Ecol. Syst.)

Using experiments to predict ecosystem responses to flow changes

- Provides direct evidence of flow effects
- Sometimes possible to obtain more accurate measurements of near-bed flow characteristics
- Permits analysis of responses to flows of interest
- Controls for variations in potentially confounding factors (e.g., seasonality)
- Helps in corroborating or refuting correlative evidence

Can experiments help determine flow pulses required to reduce nuisance algal growths?

- ♦ Background regarding pulsed flow study
  - Jackson River, VA downstream from Gathright dam
  - Nuisance algal growths contribute to DO sags
  - Does stable summer-fall low flow regime below dam exacerbate nuisance growths?
- ♦ Conducted experiments to define low flow pulses for reducing algal biomass
- ♦ Experimental results can yield useful stressor-response relationship for prescribing pulsed flows

(Flinders and Hart, unpublished)

Nuisance algal growths in the Jackson River, VA

Experimental design for pulsed flow study

- Allowed algae to accrue on artificial substrates in river
- Transplanted substrates into 10 streamside flumes
- Quantified initial algal biomass in each flume
- Applied different pulsed flows to each flume, spanning velocities from 20 (control) to 240 cm/s
- Quantified final biomass remaining after pulsed flow
- Examined relationship between final biomass and treatment velocity

(Flinders and Hart, unpublished)

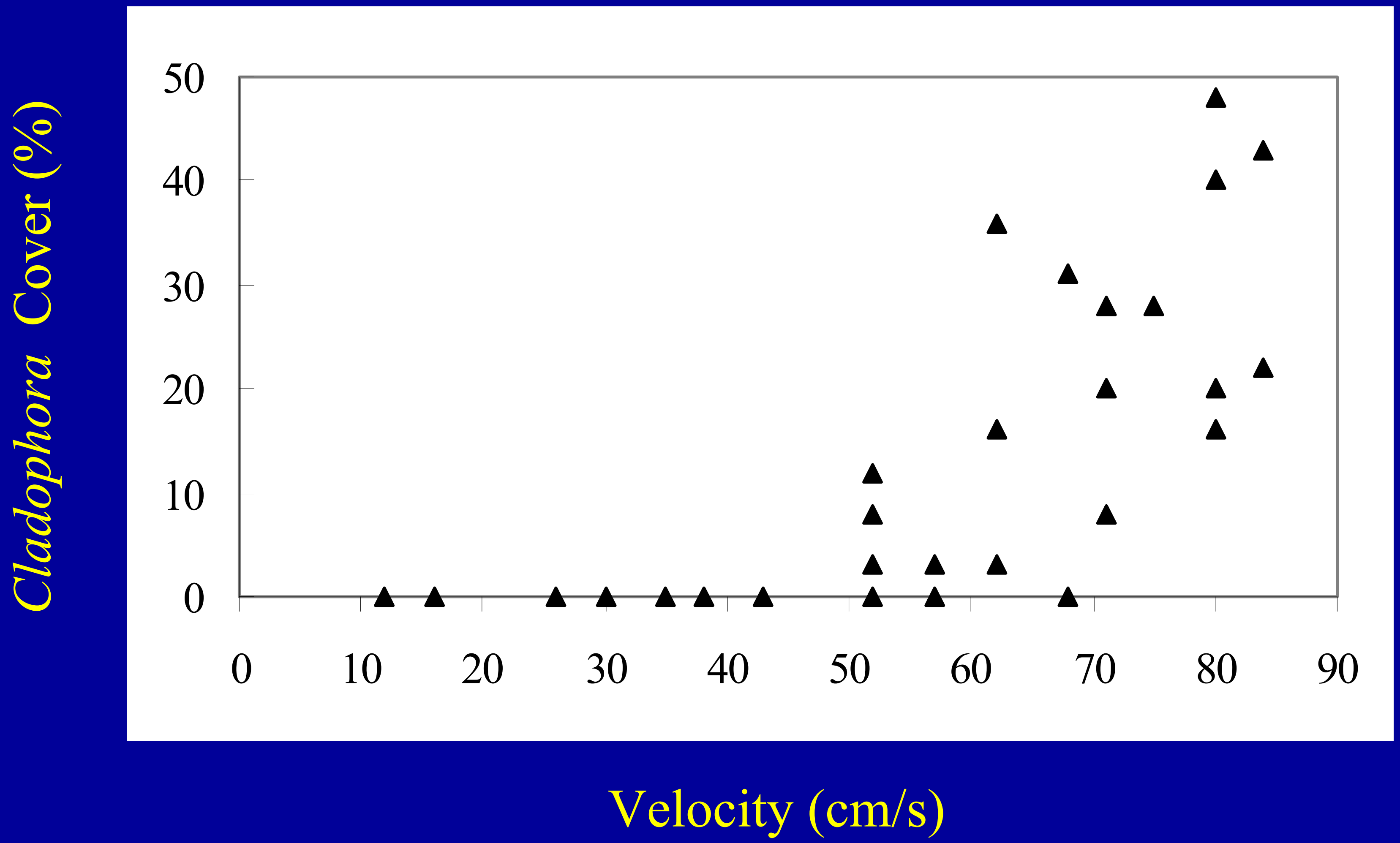
Stream-side flumes used to estimate flow pulses required for reducing nuisance algal growths

Results of pulsed flow experiment

(Flinders and Hart, unpublished)

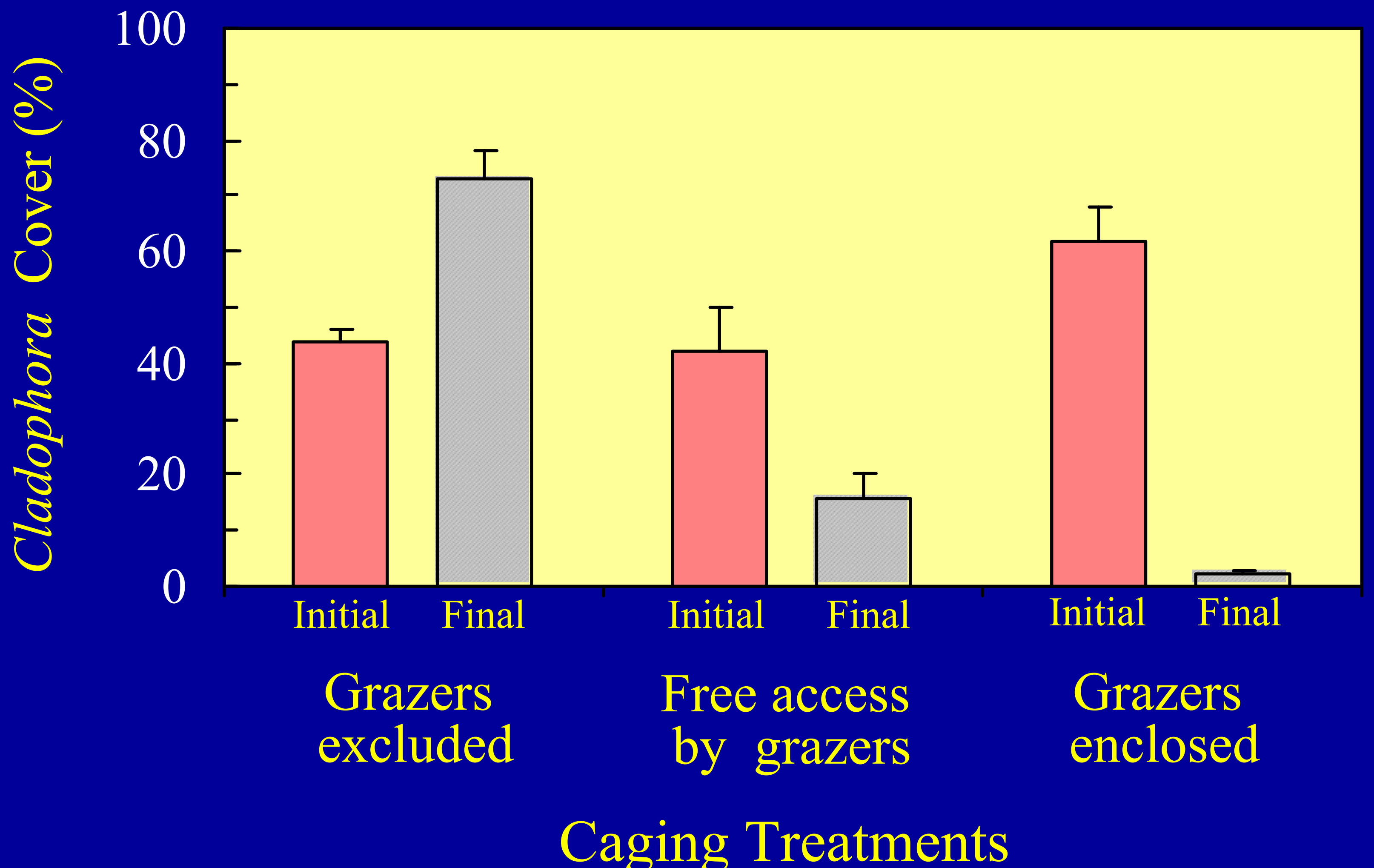
- Initial algal biomass was similar in all flumes
- Final biomass was similar to initial biomass for velocity treatments < 100 cm/s
- Final biomass significantly less than initial biomass for velocity treatments > 100 cm/s
- Final algal biomass exhibited strong negative relationship to peak velocities created during pulsed flows ($r^2 = 0.69$)
  - Ten-fold biomass reduction from lowest to highest velocity
- This stressor-response relationship could be used to determine flow releases required to reduce nuisance algal growths

Are microhabitats with velocities < 50 cm/s unsuitable for *Cladophora* growth?



(Hart 1992. Oecologia)

Cladophora's absence from low velocity microhabitats is due to heavy grazing pressure, not unsuitable velocities *per se*



(Hart 1992. Oecologia)

Changes in flow management can serve as whole-ecosystem, quasi-experiments

- Flows have been changed in hundreds of rivers to achieve various management goals
- But ecological responses have seldom been monitored
- Optimal sampling designs for quantifying ecological responses to flow changes require adequate spatial and temporal controls

500 km of TVA tailwaters impaired due to low dissolved oxygen and low minimum flows below hydropower dams

- Low DO due to hypolimnetic releases
- Low flow during non-generation periods
- Reservoir Releases Improvement (RRI) Program (~ $44 million) begun in 1991

(Bednarek and Hart. 2005. Ecological Applications, *in press*)

Ecological responses to TVA dam mitigation: "experimental design"

- Structural and operational changes at 9 TVA dams
  - Various aeration methods used to increase DO
  - Increased minimum flows during non-generation periods
  - Experimental treatments
    - Before any flow or DO change **(B)**
    - After flow increase, but before DO increase **(BDO)**
    - After flow and DO increase **(A)**
- Yearly samples of benthic macroinvertebrates (1990-2000) in three tailwater stations below each dam
- ANOVA used to test for treatment effects

(Bednarek and Hart. 2005. Ecological Applications, *in press*)

Effect of TVA dam mitigation on minimum velocity

Flow before RRI (12 cfs)

Flow after RRI (90 cfs)

(Bednarek and Hart. 2005. Ecological Applications, *in press*)

Effect of TVA dam mitigation on abiotic factors

- Significantly higher minimum discharge and minimum velocity in tailwaters following increased flow treatment
- Significantly higher dissolved oxygen in tailwaters following increased DO treatment
- No significant increase in temperature following dam mitigation

(Bednarek and Hart. 2005. Ecological Applications, *in press*)

Effect of TVA dam mitigation on benthic macroinvertebrates

- Most biological metrics exhibited significant responses to both increased flow and increased DO
- All these responses were consistent with improved ecological integrity
- Biological improvements occurred despite continuing severe hydrologic alteration
- Increased minimum flow did not result in as much biological improvement as combination of increased flow and increased DO

(Bednarek and Hart. 2005. Ecological Applications, *in press*)

Using experiments to develop and validate instream flow models

- ♦ Clearly demonstrate ecological responses to flow changes
- ♦ Sometimes difficult to extrapolate from small-scale experimental results to whole-system behavior
  - But many whole river “experiments” go unstudied!
- ♦ Predictions based on experimental results often have more certainty, but less generality and transferability
- ♦ Decision-making contexts favoring experimental approaches
  - A focus on species of special concern
  - Contentious stakeholders deliberations